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DEPLOYMENT SYSTEM FOR 50+ CUBESATS

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In recent years there has been a proliferation of CubeSats due to their low cost, standardized design and short development time. They are attractive as technology demonstrators for Universities and emerging nations. International and Government agencies are now also showing an interest, particularly in higher performance nanosats with 3U or more. However, with the increasing demand, comes a need to find a way of launching large numbers of CubeSats. The aim of this study is to design a deployment system to deliver fifty or more CubeSats together. The study commenced with a review of the deployment mechanisms currently available, such as the P-POD, T-POD, X-POD, ISI-POD, CSD and J-POD systems, as well as auxiliary launch adaptors. CubeSat build standards and Launcher requirements were then reviewed to provide a set of requirements for the design. The aim was to be compatible with as wide a range of launchers as possible. Three design options were prepared to meet the design requirements: the “Cube”, the “Tower” and the “H”. Key features of the different designs are detailed and the options were traded. Requirements and state of the art for the door opening and the delivery mechanism were also subject to a trade-off. The design selected was that of the “H” deployment system. The “H” has a versatile structure with detachable auxiliary panels. It offers a capacity of 72 CubeSats in its standard configuration or 12 lots of 6U units in its alternate configuration. It is compatible with Vega, Soyuz, Rockot and PSLV. It is hoped that eventually this design will create an opportunity for launching a multitude of CubeSats in the future.

I. INTRODUCTION

Miniaturisation of satellites has become a growth sector for the Space Industry. The success of CubeSats over the last decade is testament to this. CubeSats are designed with specific dimensions of 100 x 100 x 100mm and mass of 1kg. This is described as a 1U (Unit CubeSat). There are 2U and 3U CubeSats which have 100 x 100 x 200mm and 100 x 100 x 300 mm, weighs 2kg and 3kg respectively. The CubeSat design provides a framework which utilises a standard bus and commercial off-the-shelf components. These are less expensive to produce and have lower mass and size than space qualified components, which significantly reduces the cost [1,2]. CubeSats are usually launched on cheaper launch vehicles (LVs) or as piggyback payloads on larger vehicle with excess capacity. This standardisation and flexibility simplifies future design processes and enables the CubeSat to be made in a short development time and launched at the relatively cheap cost of approximately \$65,000-\$80,000 [3]. An increasing demand for CubeSats is anticipated over the next decade.

With technology innovations in miniaturisation over the past decade, smaller components are being used in CubeSats which will lead to higher capabilities and wider applications. This has led many universities and independent companies to start building their own CubeSats for uses such as technology demonstration, Earth remote sensing, and scientific research [4]. Until July 2013, there have

been approximately 105 CubeSats launched into space, with many future projects planned. For example, several constellations demanding a large quantity of CubeSats to be launched at once are being studied. Two examples of such projects are: QB50, where 50 2U CubeSats are proposed to be launched all together in 2014 and NASA’s Educational Launch of Nanosatellites (ELaNA) which supports several universities to launch their own CubeSats [5,6].

The most common deployment system for 1-3U CubeSats is the Poly Picosatellite Orbital Deployer (P-POD). The P-POD is an aluminium, rectangular hollow box with a door and spring mechanism. The CubeSats are stored within the box and slide along a set of rails to be deployed into orbit. The P-POD has a maximum capacity of 3U which can accommodate any combination of 1U, 2U, 3U CubeSats together [7]. However, using multiple P-PODs is problematic when a larger quantity of CubeSats are deployed; the volume and mass of the deployment system becomes disproportionate. For example, in the case of QB50, 50 2U CubeSats are planned to be launched together, therefore 50 P-PODs are required (or 25 customised 4U P-POD); integration of this many P-PODs with the LV introduces further complexity.

The solution to this challenge is to provide a single deployment system to accommodate 50 or more CubeSats. The aim of the new deployment system is to accommodate 1-3U CubeSats and larger 6U CubeSats to increase the flexibility of the design.

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II. THE CUBESAT STANDARDS

The CubeSat uses a very specific standard which restricts the design of any CubeSat deployment systems. The aim of this section is to provide a general understanding and background information on CubeSats and their deployment systems.

II.I CubeSat Dimensions

The standardisation of the CubeSat provides an efficient framework to reduce the development time and the costs of design, construction and launch. The main features are the four deployment rails at each corner which allow the CubeSat to slide out smoothly out from P-POD, an access port on the side and deployment switches at the ends of two of the four corner rails. When the CubeSats are stacked on top of each other in a P-POD, they are separated by spring plungers and are switched off to prevent any electrical interaction with the LV [8].

In 2011, bigger CubeSats were introduced of 6U, 12U and 27U [9]. Australia has shown interest in using the 6U CubeSats [10]. The 6U+ CubeSats also have their own unique deployment mechanisms which are quite different from the smaller CubeSats. Table 1 and Figure 1 show the exact dimensions, mass and appearance of different types of CubeSats. Note that the rails extend out from both sides of the cube structure, so the Z dimensions are slightly longer.

CubeSat Unit	Dimensions (mm)			Mass (kg)
	X	Y	Z	
1U	100	100	115	1
1.5U	100	100	172.5	1.5
2U	100	100	230	2
3U	100	100	345	3
6U	106.6	239.4	366	12
12U	219.7	239.4	366	24
27U	332.8	352.5	366	54

Table 1: Summary of the CubeSat standard dimensions

II.II CubeSat Missions

Orbital altitudes of launched CubeSats were reviewed in order to determine the suitable LVs. The information was based on 105 CubeSats that had been launched into space via a LV; hand launching from International Space Station has not been considered due to lack of use of deployment mechanism. All altitude values were taken as the apogee of each orbit and where multiple identical satellites of the same type were launched, they were considered as a single mission [11,12,13,14].

All the CubeSats were launched within Low Earth Orbit (LEO); the majority were within 600km-825km

Sun-Synchronous Orbit (SSO) with inclination around 98° (see Tables 2 and 3). SSO orbits have advantages for Earth Remote sensing. 1U CubeSat size is the most frequently used structure. No 6U+ CubeSats have yet been made or launched.

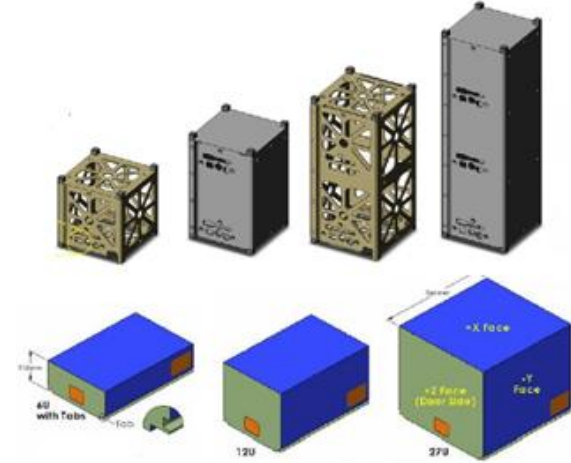


Figure 1: The CubeSat standard ranging from 1U, 1.5U, 2U, 3U, 6U, 12U & 27U

Type of Orbit	No. of CubeSats
LEO 200km-350km	11
LEO 351km-599km	21
SSO 600km-825km	65
826km-2000km	8

Table 2: Summary of the CubeSat orbital altitudes

CubeSat Unit	No. of CubeSats
1 U	72
1.5 U	2
2 U	5
3 U	26

Table 3: CubeSats sizes in previous missions

II.III Deployment systems for 1U to 3U

The purpose of the deployment system is to provide a safe contained environment and a simple deployment mechanism to launch the CubeSats. There are 8 existing types of deployment systems for CubeSats up to 3U in size. These are *Poly Picosatellite Orbital Deployer* (P-POD), *Tokyo Picosatellite Orbital Deployer* (T-POD) [15], *eXperimental Push Out Deployer* (X-POD) [16], *Single Picosatellite Launcher* (SPL) [17], *ISIS Payload Orbital Dispenser* (ISIPOD) [18], *JAXA Picosatellite Orbital Deployer* (J-POD) [19], *Canisterized Satellite Dispensers* (CSD) [9], and *Earth2Orbit Picosatellite Orbital Deployer* (E-POD) [20]. The P-POD, T-POD and X-POD were the first deployment systems to be made. T-POD and X-POD had the same objective of developing a standard deployer and they were used in the early stages of CubeSat

development. However, P-POD became the main deployment system and it is the most frequently used deployer. Figure 2 shows all of the deployment systems and their key features are summarised in Table 4.

The P-POD has the most flight heritage; it has flown on Rockot, DNEPR, Minotaur, Falcon I, STPS26, Falcon 9, Taurus, Delta II, Atlas V, Antares, Long March, Soyuz and Vega. The P-POD has a hollow tube design with deployment rail tracks at each corner along the length, these rail tracks are formed by small protruding flanges on adjacent inner surfaces (see Figure 2c); they ensure the CubeSat is retained in a stable position and provide a smooth surface for the CubeSats to slide on. The CubeSats are pushed down through the tube and rest on top of a spring platform which holds the elastic energy for deployment. A spring-loaded door encloses the CubeSat and it can be released with a bolt separation or split spool-based system. The internal dimensions are 100mm x 100mm x 340mm. A double P-POD design has a capacity to hold up to 6 units of CubeSats (however it is not a 6U deployment system) and utilises a common mid wall to save mass. The P-POD is made of Aluminium 7075-T73 with Teflon impregnated hard anodized. The mass of a single P-POD is 5kg pre-deployment and 2kg post deployment [21].

All the other deployment systems utilise the same spring and rail mechanism to propel the CubeSats. They also follow the strict CubeSat standards and dimensions. However the door release mechanisms, the general shape and accommodation arrangement of the CubeSat may be different.

Design	Country of Origin	First Model	Maximum Capacity	Flight Heritage	No. of Units used
P-POD	USA	2003	3U/6U	19 times	48
T-POD	Japan	2003	1U	Twice	7
X-POD	Canada	2008	3U+	Twice	8
SPL	Germany	2009	1U	Once	4
ISIPOD	Netherlands	2009	3-5U	Once	2
J-POD	Japan	2010	4U	Once	1
CSD	USA	2011	3U	None	0
E-POD	India	2011	3U	Once	1

Table 4: Summary of all deployment systems for 1-3U CubeSats

II.IV Deployment systems for 6U to 27U

The CSD is a family of deployment systems that can accommodate a single 6U, 12U or 27U CubeSat. The CSD uses a payload tab deployment method (further discussion in section III.II). Currently no 6U+ CubeSats have been launched and there is no

flight heritage from any CSD [22]. Wallop's 6U Deployer is an alternative. It provides a unique lateral and axial constraint system but requires changes to the CubeSat standard structure [23]. There are no other 12U and 27U deployment systems available.

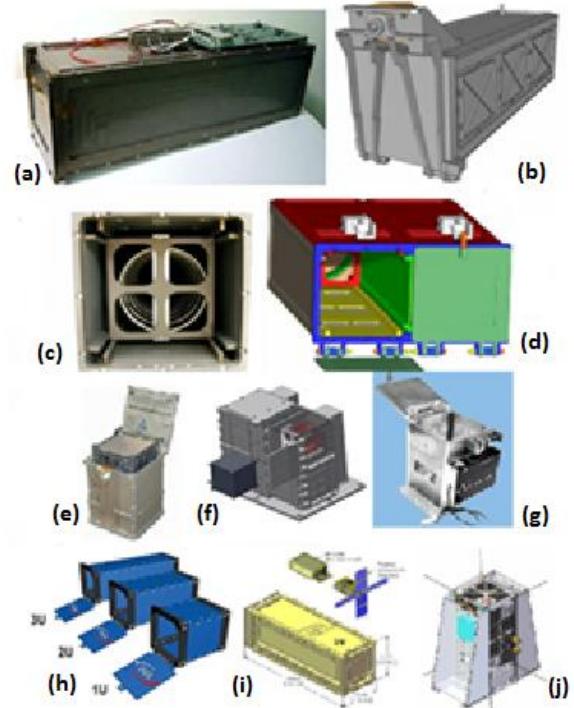


Figure 2: (a) P-POD MK-I, (b) MK-III, (c) P-POD Interior, (d) Double P-POD. (e) SPL, (f) J-POD, (g) T-POD, (h) ISIPOD, (i) CSD, (j) X-POD

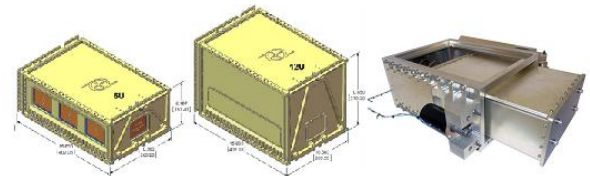


Figure 3: Image of 6U and 12U CSD (Left), Wallops 6U Deployer (Right)

II.V Auxiliary Payload Adapters

Intermediate structures are available to provide ways in which multiple P-PODs could be mounted together such as the ESPA Ring (Evolved Expendable Launch Vehicle Secondary Payload Adaptor) [24] and the Naval Postgraduate School CubeSat Launcher [25]. These container structures can hold up to around 8 P-PODs (24U capacity of CubeSats), however, special interfaces with the LV are required.

III. DESIGN DRIVERS AND CONSTRAINTS

The New Deployment System (NDS, the name of this new design) is heavily restricted by the CubeSat deployment mechanism and dimensions. However, mass and capacity are optimised throughout the design process. The P-POD was used as the benchmark for comparison throughout this study.

III.I Design Drivers

Increase the Maximum Capacity

The maximum capacity for P-POD is no more than 3/6U CubeSats. The whole purpose of this study is to increase the capacity to accommodate 50 or more CubeSats at once. This is the primary driver for the design.

Optimise Mass and Volume

Minimising mass and volume will minimise launch cost and increase compatibility with more LVs.

Single Structure

A single structure would save mass and volume due to an integrated design that utilises shared components. In addition, a single deployment structure would not require any auxiliary payload adapter since it is big enough to be directly attached to a payload platform as a secondary payload.

Accommodation of 1-3U & 6U CubeSats

Both the 1-3U and 6U CubeSats share the same deployment rail mechanism and structure type [9]. Using this common feature, the NDS can incorporate the newer 6U CubeSats in conjunction with the original 1-3U CubeSats; this would attract more clients and create more opportunities for CubeSat launches.

Increase Launch Vehicle Compatibility

The NDS should be compatible with a range of LVs to enable a wider launch opportunity.

Simplicity of Deployment Mechanism

The P-POD door release mechanism is the most likely point of failure observed from previous CubeSat missions. An alternative, possibly more reliable, solution is chosen for the NDS. Key mechanism tradeoffs are discussed further in section V.

III.II Design Constraints

The CubeSat Standard

The standard requires the CubeSats to conform to a specific set of dimensions. The interior of the NDS would also need to have strict dimensions to match with the CubeSats'.

Access Port

Each CubeSat situated inside the NDS would be required to have at least one face accessible externally. For example, this would restrict the design

in a 3x3 formation where the middle CubeSat cannot be accessed due to surrounding CubeSats.

Launch Vehicles

Each LV has a limited mass and volume available to accommodate the primary payload and the NDS. The available accommodation is heavily dependent on the mission profile and the risks associated with secondary objectives. The NDS should not increase any baseline risks to the primary mission due to its status as a secondary payload. To ensure the NDS is compatible with certain LVs, an upper mass limit is used for all conceptual designs.

IV. LAUNCH VEHICLE COMPATIBILITY

CubeSat missions are generally used in LEO and often in SSO orbits. A range of LVs are investigated to distinguish the best LV available for a piggyback mission to carry the NDS. Due to the large scope of this study and from a European origin, the focus will be on European LVs. This study examined ESA's VEGA and Soyuz-2 as the primary LVs. Polar Satellite Launch Vehicle (PSLV) which is the LV with highest flight heritage with CubeSats and Rockot were considered as well.

Launch vehicle capacity was compared with actual spacecraft mass to find out if there were excess capacity for a multiple CubeSat piggyback mission. The parametric studies used satellite mass and orbital altitudes [11,26]. The estimated maximum launch masses were extrapolated from orbit altitude vs. maximum lift-off mass graphs from relevant LV manuals.



Figure 4: VEGA with SSUP (Left); Soyuz with ASAP5 (Centre); PSLV in piggyback mode (Right)

IV.I VEGA

VEGA is suitable to deliver payloads to LEO and can launch a maximum payload capacity of 1500kg to 700km altitude. VEGA had its maiden flight at the end of 2012 with a payload mass of 420kg. Figure 4 shows the final assembly within the payload fairing where LARES, ALMASat 1, and seven CubeSats are placed upon LARES Support Subsystem (SSUP) [27]. VEGA could launch many microsatellites and CubeSat deployment systems using a multiple payload platform that is similar to SSUP. [28].

IV.II Soyuz-2

Soyuz-2 is a medium class LV that can launch 4850kg to LEO, 4400kg to SSO and Polar orbits and 3250kg to Geostationary Transfer Orbit (GTO). It launched three CubeSats in spring 2013 to 600km altitude. Soyuz also provides an auxiliary payload platform called Arianespace System for Auxiliary Payload (ASAP-S) that has capacity of four microsattellites of 200kg class each on the external position and one mini satellite of 400kg class in the central position. This structure can (Figure 4) accommodate Pleiades-1, SSOT and 4 ELISA [29].

Figure 5 shows a parametric study of how much excess mass was available during previous Soyuz missions. There have been 20 launches in total, 10 different launch scenarios (some had repeated launches for multiple commercial satellites such as Galileo and Meridians); two launch scenarios for Kosmos 2441 and Zenit-8 were not included due to exceeding maximum payload mass. Figure 5 shows four launch scenarios out of six have over 500kg excess mass. Figure 5 excludes launches from Medium Earth Orbit (MEO), other assumptions include:

Excess mass = launch capacity-launch mass of s/c

Launch mass = wet mass of s/c + adapter/dispensers

Mass of normal adapters are averaged to 120kg, dual dispensers 180kg, 6 s/c dispenser 630kg

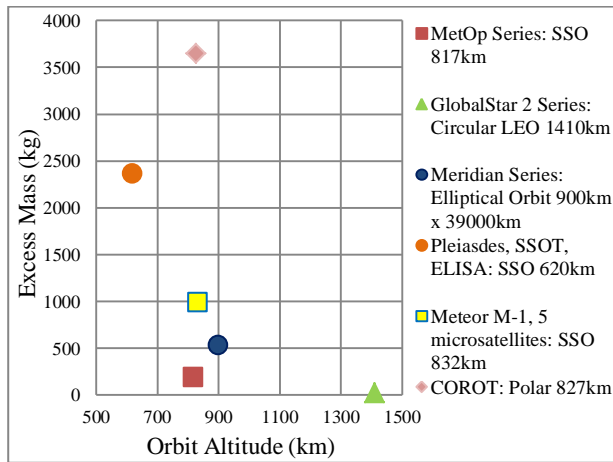


Figure 5: Excess mass for 6 Launch Scenario to LEO

IV.III Rockot

Rockot is a lightweight LV similar to VEGA; it has 20 flights heritage and 18 successes. It has the capability to launch 1400kg to 800km circular orbits and 1150kg to 800km SSO. Rockot does not have a normalised platform for multiple auxiliary payloads but it has performed 1 flight for a CubeSat mission. Figure 6 shows that there are excess masses of over 200kg in almost all Rockot flights. Even though

Rockot has no standardised auxiliary payload platforms, it has great potential in accommodating multiple satellites in a single launch and has enough excess capacity to CubeSat missions [30]. The assumptions for Figure 6 were:

Launch mass = wet mass of s/c + adapter/dispensers

Adapters are 10% of total s/c mass

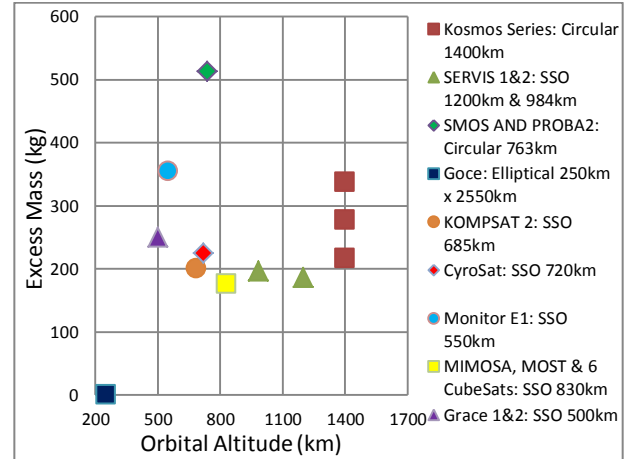


Figure 6: Excess mass for Rockot Launch Scenarios to LEO

IV.IV Polar Satellite Launch Vehicle

PSLV is a lightweight LV; it has 23 flights heritage and 21 successes. There are currently 3 LV variants: standard PSLV has capability to launch 1678kg to 622km SSO, "Core Alone" PSLV-CA has capability up to 1100kg and up rated PSLV-XL has extra solid booster propellant to carry 1800kg. PSLV can accommodate two auxiliary payloads in every flight in piggyback mode. This is a natural capability where it does not require an auxiliary payload platform like ASAP-S or SSUP. The mass of each auxiliary payload must be below 150kg with maximum dimensions of 600mm x 700mm x 850mm (height). Figure 4 shows the arrangement of such accommodation. PSLV has 13 previous missions accommodating many microsattellites and CubeSats [31].

V. MECHANISMS TRADE-OFF

V.I Deployment Mechanism Trade-Off

The key mechanisms within the NDS are the deployment and door release mechanisms. The deployment mechanism can be split into two distinct features; firstly, how the CubeSats are retained within its confined space inside the NDS and secondly, how the CubeSats are ejected from its stationary position.

The retaining mechanism during pre-deployment for 1-3U CubeSat deployment systems consists of deployment rails. For 6U+, both the CSD and Wallop

systems use two different mechanisms. Only the 6U CubeSat has the choice of either having rail or payload tabs deployment mechanisms depending on the CubeSat structure chosen. These are summarised in Table 5.

Design	Size	Features
P-POD	3U	<u>Deployment Rails</u>
	6U	The P-POD has protruding flanges in the inner walls at right angle to form rail tracks at each corner. The interior has a confinement of 100mm by 100mm hollow square column where the CubeSats have a sliding fit with the P-POD.
CSD	6U	<u>Payload Tabs</u>
	12U	The CubeSat structure has a pair of thin flanges extruding out on both sides along its length; these are the “tabs” in which the CSD structure grips onto prior to deployment. The excessive chatter in between the payload and the deployment structure is reduced.
	27U	
Wallops Deployer	6U	<u>Pin Constraints</u> Slotting pins at the key positions at the top and the sides of the CubeSat structure into the Wallops interior creates a more predictable loading environment.

Table 5: CubeSat stationary constraints

NDS shall use the same deployment rail system as the P-POD to deploy CubeSats in a linear straight path; this is to maintain the same deployment mechanism for 1-3U CubeSats. If the other two deployment mechanisms are used, then it will not be compatible with 1-3U CubeSats standard.

All the deployment systems utilise a spring platform to store and release the energy. However, other possible methods of using energy to thrust the platform exist, such as compressed gas and shape memory materials. The pros and cons of these methods are summarised in Table 6.

Method	Advantages and Disadvantages
Compressive Spring	✓ Efficient energy storage
	✓ Immediate response after door is released
	✓ Simple and easy to use
	X Larger volume in stowed position
Compressed Gas	✓ Higher energy release
	✓ Compact
	X Requires air-tight interior
	X Requires separate trigger

Shape	✓	Higher amount of energy
Memory	✓	Lower volume storage
Material	X	Heat or chemical trigger release

Table 6: Summary of energy release methods

The two new methods both have a higher efficiency in terms of power and storage space. However, the spring mechanism was chosen as it does not require a separate trigger and it is the simplest to implement.

V.II Door Release Mechanism

The Hold-Down and Release Actuator (HDRA) and is one of the major factors that differentiate between deployment systems. This one-shot mechanism deploys the CubeSat and it requires high reliability. The chosen HDRA needs to generate low shock levels. A trade study was conducted to find out the most suitable for the NDS and the advantages and disadvantages of each HDRA are stated in Table 7.

HDRA Type	System	Features
Vectran Line Cutter	P-POD MK-I	• Pyrotechnic wire cutter
		• Non-reusable
		• Requires a temperature up to 300°C
		• Requires volume on the external surface
Separation Nut & Split Spool	P-POD MK-II	• Reliable
	MK-III	• Partially mechanical
		• Partially reusable
Electro-magnetic Clamp	SPL	• Utilise electric pulse signal to trigger door release
		• Reusable/self resetting
		• Lower reliability
Electric Motor/ Latch	CSD	• Electric DC brush motor to initiate the release of latch door
		• Long lead screw
		• Reusable/self resetting
		• Small storage
		• Higher mechanical risk

Table 7: List of HDRA and their features

An electric DC brush motor was selected as the HDRA to initiate the release of a latched door. This mechanism system was chosen because it offers flexibility as to its location. All other devices require a direct interaction either on the adjacent surface or directly next to the door to provide the release, however the electric motor can be placed away from the latch.

VI. PRELIMINARY CONCEPTUALISATION

The three alternative conceptual designs were called the “Cube”, the “Tower”, and the “H”. There were some key design features that are prominent in all three ideas.

VI.I Design Drivers

CubeSat Accommodation

The minimum CubeSat size is 1U, the maximum CubeSat size shall be 6U. The sole reason for this is to increase the flexibility of NDS to accommodate a variety of payloads.

NDS Structure

The structure comprised several rectangular tube columns arranged side by side in different formations. All CubeSats shall be enclosed from all sides to be protected prior to deployment. Each design would allow adequate spaces for access areas to be reached from the outer perimeter. The arrangement of rectangular column will provide the most space efficient way to deliver the highest capacity of CubeSats.

NDS Structural Depth

The depth of the structure was increased from 3U to 6U; the increased in depth provides double the capacity along the column length so it can accommodate two 3U CubeSats.

Deployment Mechanism

The selected deployment method was a one-shot spring mechanism that pushes the CubeSats out (similar mechanism as the P-POD). The latch door release mechanism is operated by an electric DC brush motor.

Material

The material currently selected was the same as that used for CubeSats in order to minimise differences in Coefficient of Thermal Expansion: Aluminium 7075-T73. To reduce mass, carbon fibre composites could be considered, but these may introduce integration issues.

Versatile Structure

Removable auxiliary panels (Figure 7, panels in teal colour) were used to separate adjacent columns. In the standard form, each design structure would only carry 1-3U CubeSats, while in the augmented form, auxiliary panels could be removed to allow 6U CubeSats to fit within two columns; therefore, a mixture of 1-6U CubeSats could be fitted.

No External Devices

No external components or devices are exposed outside of the perimeter around any columns. This is to ensure that there was no interference when multiple tubular columns are attached to each other on multiple sides.

VI.II Preliminary Designs

The “Cube”

Designed to have the highest capacity, this had a shape of 5U by 6U cuboids. However, to improve CubeSat accessibility, the design incorporated a 2U by 3U hole to enable access to the inner columns. The structure would accommodate 144U of CubeSat and a maximum mass of 288kg worth of payload. The size of the structure and its mass of over 320kg, would severely limit the LV compatibility.

The “Tower”

Designed to be a compact; it would hold the highest density of CubeSats. The structure was designed to be a 3U by 3U cuboid with the mid-centre column is removed to improve accessibility. It could store up to 48U of CubeSat for 14kg of mass. In the scenario of a pure 6U CubeSat mission, not all the columns could be filled with 6U CubeSats.

The “H”

Designed to be a medium capacity deployment system; it has an “H” shape with a formation of 4-2-2-4 rows. There were 12 columns in total; they were enclosed by 6 double sized doors. The design could accommodate 72U of CubeSats with a payload mass of 144kg. The structure provides the same versatility as the “Cube” with full 1-3U, 6U, or mixed missions. The overall total potential mass would also be less than 200kg and therefore it had good LV compatibility.

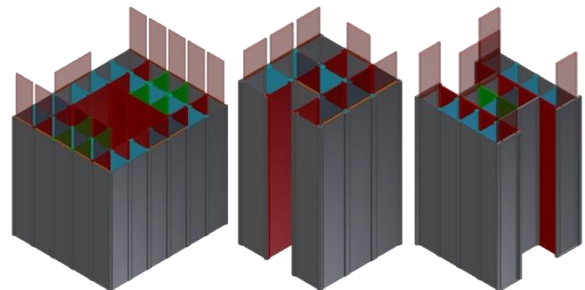


Figure 7: The “Cube” (Left), The “Tower” (Centre), The “H” (Right)

The “H” design was chosen to be the conceptual design and was refined.

VII. NDS DESIGN

General Layout

Figure 8 shows the engineering drawings for the design. The materials selected for manufacture were Al 7075-T73; the empty mass of the design was 55kg (including a 20% margin). The outer perimeter dimensions of the design were 506mm by 500mm by 819mm. The interior layout was split into six sub-system “compartments” of 120mm x 240mm x 684mm and they provide the enclosure for two columns of CubeSats. Each compartment can be

divided further into two smaller tubular columns by using auxiliary panels.

Deployment Method

The deployment mechanism consisted of a compressive spring platform where the CubeSats can rest on. Each compartment/column had a set of compressive spring and platform. Spring latched doors were used to retain the compressive energy in the spring. In total there were six doors, one each for every compartment, therefore one door retained the energy for two columns. The latch door release mechanism was operated by a Moog size 8 permanent magnet DC motor which was situated at the top of the structure, near to the latch.

Normal and Augmented Configuration

In the normal configuration (with auxiliary panels in place), the NDS had 12 columns and it could accommodate up to a total of 72 1U CubeSats. Each column had a containment volume of 100mm x 100mm x 684mm to accommodate 6U worth of CubeSats. In each column, there would be a compressive spring of 100mm in diameter with 782mm in length. In total 12 springs were used.

In the augmented configuration (without auxiliary panels), the NDS had 6 compartments and it could accommodate up to a total 12 6U CubeSats. Each compartment had a containment volume of 100mm x 220mm x 684mm to accommodate two 6U CubeSats. In each compartment, the two sets of spring platform were replaced with a single platform attached to a square spring of 100mm x 220mm with 782mm in length. In total six square springs were used.

General Assembly

Figure 9 shows the exploded view of the full assembly of NDS. The base structure provides the main interface between the NDS and the LV. In addition, all panels were assembled and bolted onto the base plate. All outermost panels had a thickness of 1.5mm and the inner auxiliary panels had a thickness of 1mm to reduce mass. There were 72 access openings on the outer faces of the NDS to provide CubeSat access. After the CubeSats were installed within the NDS, the access openings were covered by 24 access panels (Figure 9).

Other Features

The main electrical supply was supported by the LV and each compartment had a normal DB9 socket connection positioned at the bottom of the base structure due to the protection provided by the base plate. Harnesses were relayed from the DB9 socket to the electric motor via the gap between the deployment rails and inside of the panels. The NDS can be launched on VEGA, Soyuz, PSLV and Rockot.

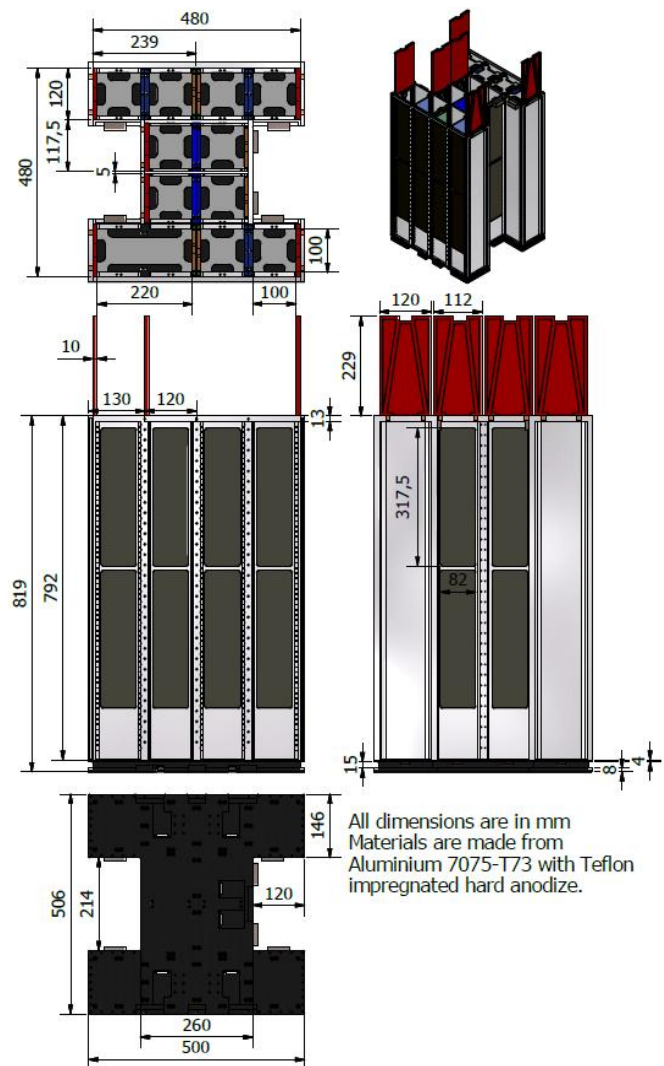


Figure 8: Drawing of the NDS

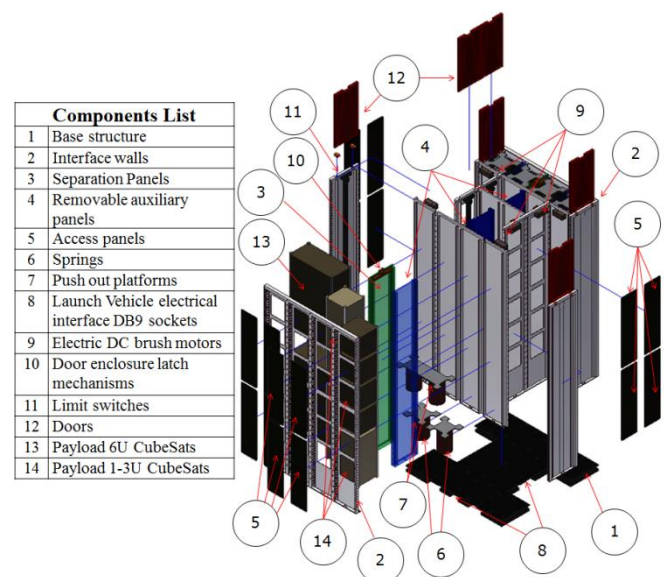


Figure 9: Exploded view of the NDS

VIII. MECHANICAL DESIGN

VIII.I Structural Considerations

Structure Stiffness

The NDS will experience the highest static loads during launch. For example, in the case of Vega, the peak longitudinal acceleration is 4.3g. For the worst case scenario, the NDS will experience a total load of 9,807N with safety factor of 1.25. Assuming the load is distributed along its length of 819mm and only the panels carry the loads, the amount of deflection is 0.173mm.

Panel Stability

The structural integrity is provided by the array of external panels shown in Figure 9. The external panels therefore form the primary load structure carrying the loads from launch. Assuming the same Vega scenario; the outermost panel will experience stress of 17.8 N/mm^2 . Designing for panel buckling due to the compressive stresses, this led to the outer panels of the NDS being sized at 120mm x 819mm x 1.5mm. The critical stress is 20.1658 N/mm^2 . The reserve factor is 1.13. To increase the stability of these panels, shear walls could be used to break the single panel into shorter pieces in the longitudinal direction, but this would increase mass.

Structure orientation and LV interface

Figure 10 shows the NDS positioned within three out of the four different LVs in comparison with a primary payload satellite. In most scenarios, NDS is likely to be positioned on a multiple payload platform specifically available to that LV. Refer to Figure 4 for a comparison with real sized launchers.

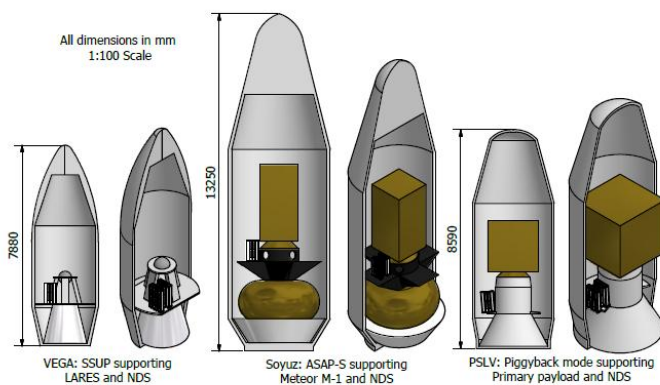


Figure 10: 3D CAD drawings of NDS placed within VEGA, Soyuz and PSLV

VIII.II Mechanisms Considerations

Spring Design Mechanism

For the standard configuration, the spring selected had an outer diameter of 100mm, wire diameter of 6.5mm, 12 active coils and a solid spring length of 98mm. The total length of the spring was 782mm and it had the capacity of 684mm of free spring. The

spring material was made from Chrome Silicon A401. At solid spring, it can provide a load of 1060N which is more than enough to hold 12kg of CubeSat in 4.3g longitudinal acceleration of 506.2N. The spring needs to be compressed and enclosed by the latch mechanism.

In standard configuration, adjacent CubeSat sizes of 1-3U within the same compartment could possibly collide. To avoid this, the two springs within the compartment would have different spring constants, to ensure that one column of CubeSats has a greater acceleration than the other.

For the augmented configuration, the auxiliary panel is removed to allow a double platform that occupies the area of a single compartment on top of a square spring. If the free length of the spring is more than four times the outer diameter then it would be susceptible to buckling [32]. Spring buckling would not be a problem in a single column using circular springs; however when the auxiliary panel separating the compartment is removed, there would be no casing around the spring. Therefore, square springs were selected.

Door Release Mechanism

Each door release mechanism is responsible for up to 12 units of CubeSat. The motor was placed at the top of the NDS in the open space on the centre column section. This keeps the lead screw length to 100mm. A limit switch was positioned directly below each door to allow monitoring of deployment.

Motor Selection

For NDS, the motor would only need to operate once after launch; therefore reuse and control of the motor is not an issue as long as it has sufficient torque to initiate the release of the latch (calculated as 53Nm). A DC brush motor was chosen over a brushless counterpart due to its size and lack of need for controllers. The Moog size 8 permanent magnet DC motor was chosen for its flight heritage and the small diameter size of 19.3mm and it has a nominal no load speed of 23,500rpm.

IX. FURTHER WORK

This report covers a preliminary study of a novel alternative to deploy multiple CubeSats. More structural and mechanical analysis is required. Once this has been performed, a prototype will be constructed and tested.

X. CONCLUSION

A New Deployment System (NDS) for launching more than 50 CubeSats simultaneously has been presented. Preliminary sizing indicates that an “H” design structure of Aluminium could be constructed to deploy 72U of CubeSats for an empty mass of

55kg. This design would be compatible with launchers such as VEGA, Soyuz, PSLV and Rocket.

XI. ACKNOWLEDGEMENTS

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